Constellation X

The Constellation X-ray Mission

# Constellation-X Formation Flying Overview


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# The Core Components of Formation Flying - The Engineering Side

| | |
|---|---|
| **Formation Design and Initialization** | **Relative Navigation** |
| **Intersatellite Communications, Time Synchronization, and Time Transfer** | **Formation Control** |

# Formation Design and Initialization

- The guidance problem for formations
  - What is the desired formation geometry over time?
- Driven directly by science mission needs
- Constrained by fuel consumption and physics
- Major driver for research in dynamics of relative motion
- Small errors in initialization can be very costly in fuel

# Relative Navigation

- The measurements between spacecraft
- Sensors and algorithms
  - includes metrology systems and wavefront error sensing systems
- Driven by science mission needs or indirectly through other engineering requirements
- Performance verification required with sensor in the loop with high fidelity channel simulator
- Constrained by technology

# Intersatellite Communications, Time Synchronization, and Time transfer

- The data bus of the formation
- Robustness and continuity is essential
- Primary development areas:
  - mass reduction
  - power reduction
  - cost reduction
  - integrated communication and ranging
- Substantial work needed in establishing requirements for communication bandwidth and time synch/time transfer for precision formation control performance

# Formation Control

- The forces and moments required to regulate or track desired formation geometry
- Actuators and algorithms
- Autonomy and higher-level command and control
- Depends on all other components
- Principle driver for concepts such as 6DOF spacecraft control and closed-loop orbit control
- Responsible for rejecting disturbances and maintaining stability
- True system-level problem
- Constrained by technology and systems engineering challenges

# Formation Modes

- Lost-in-space/initial insertion
- Coarse vehicle placement
- Coarse vehicle orientation

} GN&C

- Formation initialization
  - VISNAV/CCD/APS/modified star tracker
  - Star trackers on mirror-craft all tracking same guide star
- Capture
  - Optics spacecraft to detector spacecraft optical (possibly RF) ranging required to get to 5 mm measurement accuracy
  - Establish relative position using ranging and optical measurements
- Calibration (backing out system parameters)
- Maintenance
  - Continuous/near continuous thrusting (electric-type propulsion) on spacecraft
  - Optical ranging with modulating retro-reflectors

# Formation Flying Components (Hardware - total for 2 S/C)

- Intersatellite communication transceivers (2)
  - possibly with fine ranging to eliminate next 2 items
- Laser (1 or 2)
- Modulating Retroreflectors (2-5)
- Fine Resolution Propulsion System (2)
- Coarse (VISNAV) Formation Sensor (1)
  - could be modified tracker already on-board for other purpose
- LED beacons (5-10)

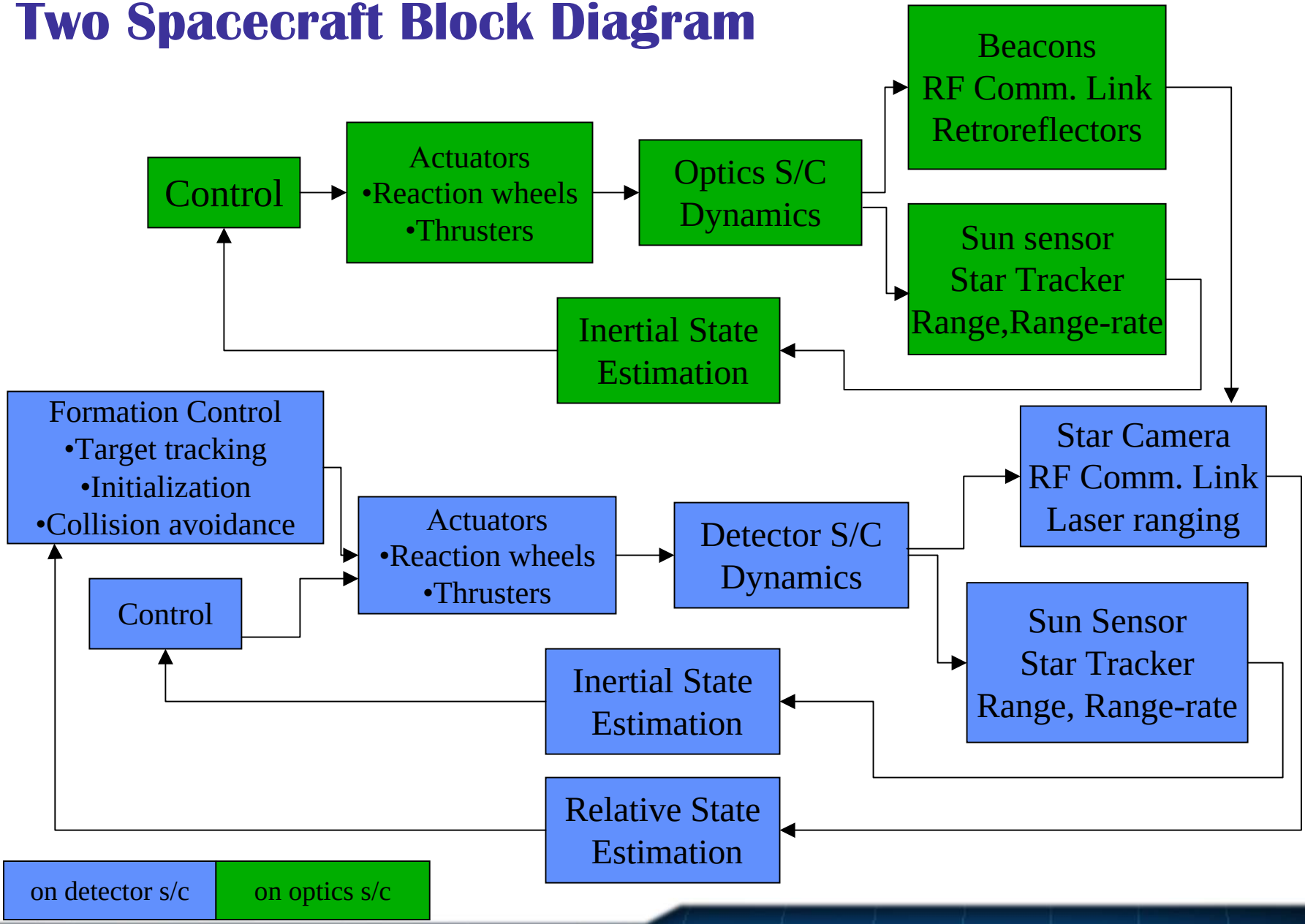
# Formation Flying Software

- **Relative Navigation**
  - Onboard absolute and real time relative navigation system
  - Adapting current onboard navigation system for multiple spacecraft poses biggest challenge
- **Formation Control**
  - More complex than typical attitude control system, requires 6 DOF control
- **Fault-tolerance, safety, collision avoidance**
  - Define safety modes (e.g. ‘safehold’ operations), re-pointing of formation and sun avoidance, power, thermal issues

# Testbeds and Validation

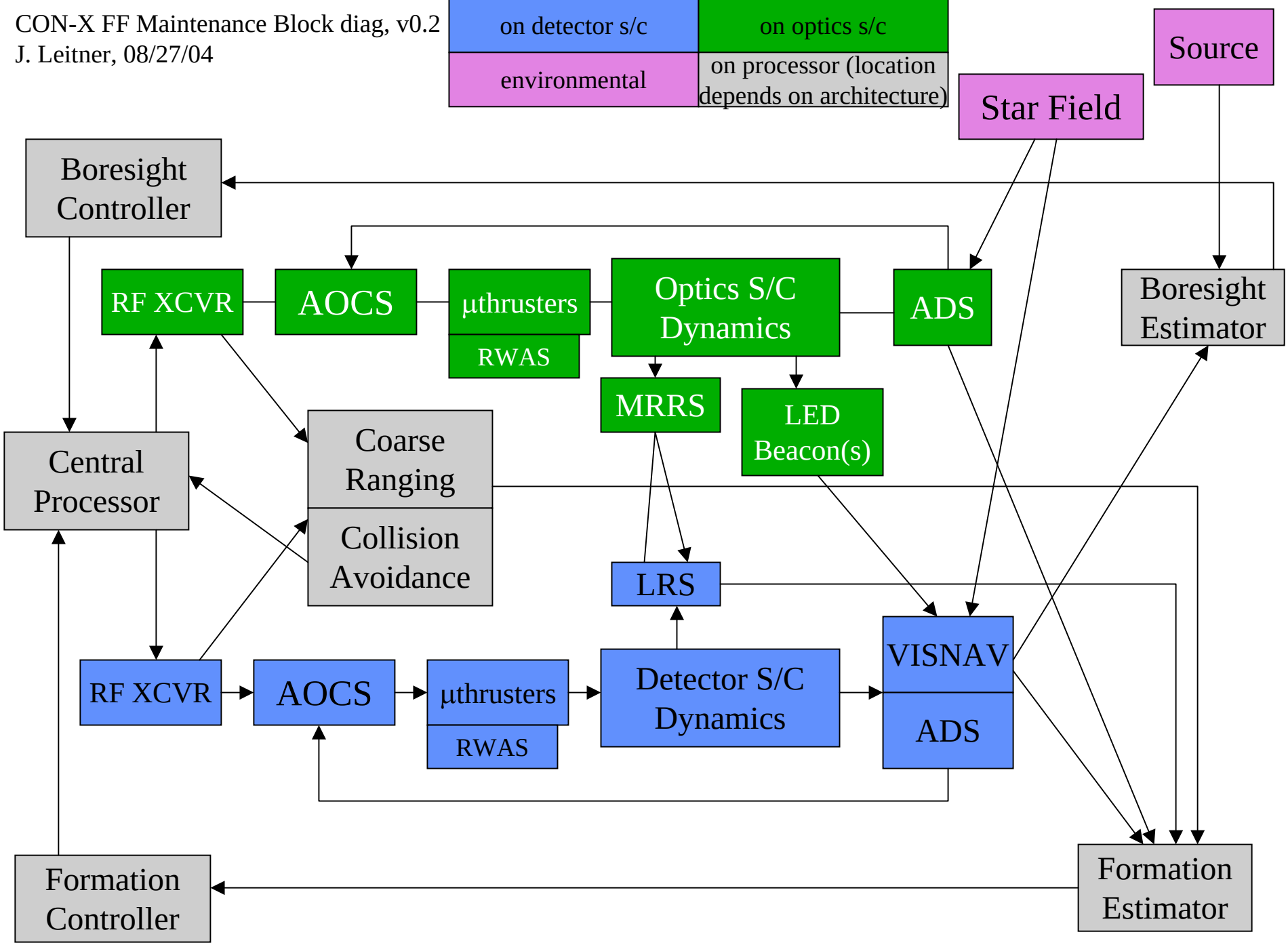
- Mission Engineering and Systems Analysis Division at GSFC has a Formation Flying Testbed (FFTB) with hardware-in-the-loop capabilities
- The FFTB is currently testing crosslink communications and formation control algorithms using multiple networked computers
- Need to verify integrated communication/relative navigation/formation control
  - Use FFTB and other locations (on availability basis)
  - Can be enhanced specifically for CON-X for about $5M
    - Integrate beacon system
    - Enhance relative navigation/control algorithms

# Two Spacecraft Block Diagram



# Extra Slides

CON-X FF Maintenance Block diag, v0.2
J. Leitner, 08/27/04



# Technology- SOA, required, and projected

| Required Capability | Figure of Merit: Now | Figure of Merit: CON-X | Figure of Merit: Long-term | Current TRL, CON-X performance |
|---|---|---|---|---|
| Number of Satellites (affects measurement, control, communications, and operations) | 2 S/C, non-collaborative (LS-7/EO-1) | 2 | >30 | 9 |
| Measure relative position | 2 cm postprocessed (over 20,000 km measurement to GPS transmitter) | 0.5 mm radial | < 1 nm on-board | 2 cm: 6<br>< cm: 4 |
| Measure S/C-S/C bearing angles (combination of relative attitude & 3 axis position) | N/A | 0.5 asec roll,<br>3 asec, pitch and yaw | 1 mas | 4 |
| Control relative position through comm. link | Rendezvous/Docking, < 1m short range | 5 mm | 3 nm | 3 |
| Control S/C-S/C bearing angle | N/A | 5 asec roll, 30 asec pitch and yaw | 10 mas | 2 |
| Formation line-of-sight Control | N/A | 16 asec (1 asec measurement) | 100 nas | 2 |
| Inter-S/C Communication Rate | 300 Mbps TDRSS | ~150 kbps | 3-10 Mbps | 9 |
| Constellation Operating Range | 1 km | 50 m | 1-500 km | N/A |
| Formation Commanding | On-board, one spacecraft relative to other | On-Board, collaborative | On-Board, collab-orative | 4 |
| Autonomous collision avoidance | N | Y | Y | 4 |
| Precision of time synchronization | 3 ns GPS, on-board real-time | 1 μs | 1 ps | 9 |